METAMATERIALS AS SUPER-SUBSTRATE TO ENHANCE DIPOLE ANTENNA PERFORMANCES

E. Sáenz, R. Gonzalo, I. Ederra
Electrical and Electronic Engineering Department.
Universidad Pública de Navarra, España
e-mail:ramon@unavarra.es

P. de Maagt
European Space Research and Technology Centre
ESTEC The Netherlands
e-mail:Peter.de.Maagt@esa.int

Abstract: **In this work, pass band properties of Left Handed Media (LHM) are demonstrated. These properties have been used in order to make a LHM super-substrate that is put over a dipole antenna. This super-substrate is going to determine the characteristics of radiation patterns. Simulations with different types of configurations are presented in order to enhance the features of radiation patterns at bore-sight direction.**

Keywords: Metamaterial (MTM), Left Handed Media (LHM), Double Negative Metamaterial (DNG), super-substrate

I. INTRODUCTION

Since Veselago predicted the existence of left-handed media (LHM) in 1968 [1], many studies have been carried out in order to construct this type of structure. Metamaterial (MTMs) denote artificially constructed materials having electromagnetic properties not generally found in nature, such as double negative (DNG) media, i.e., MTMs having negative permittivity and negative permeability.

Ziolkowski designed different types of DNG media based in a substrate with embedded capacitively loaded strips (CLSs), that produce a strong dielectric-like response, and split ring resonators (SRRs), that produce a strong magnetic material-like response [2]. These unit cells were designed with ANSOFT's High Frequency Structure Simulator (HFSS) and demonstrated that they acted as a LHM in the X band frequency. An important characteristic of these type of structures is that they can be scaled in order to change the band of frequencies at which they act as a LHM.

This paper is going to analyze the behaviour of one of these unit cells at different bands of frequencies. As it will be seen, these cells are going to have transmission and non-transmission bands that will be used in order to create a structure that acts as a filter. Therefore, power is only going to be transmitted in the pass band of the cells, i.e. at the transmission peak in the S_{21}. Out of these frequencies, power will be reflected. This property will be used to place a DNG media as a super-substrate of a dipole antenna to enhance its radiation features. High directivity patterns with low back radiation are obtained. This structure behaves as a resonator antenna.

II. DNG MEDIA

We are going to use a simplified MTM structure. The unit cell consists of one SRR between two pairs of CLSs. Note that with the symmetry walls, the actual configuration has two pairs of CLSs between two SRRs. In this case, the width of all the gaps and lines were 0.254 mm, the unit cell in the z direction was d_1=7.366 mm, the x length d_2=2.3622 mm and the y length was d_3=4.318 mm. The height of the CLS inclusions was l_1=3.81 mm, the length of the full capacitive strips was l_2=3.556 mm and the length of the half strips was l_3=1.778 mm. The length of the outer SRR was r_1=2.794 mm and the inner was r_2=1.778mm. The dielectric has a constant permittivity of ε_r=2.2. The geometry of the MTM unit cell is shown in Fig 1.

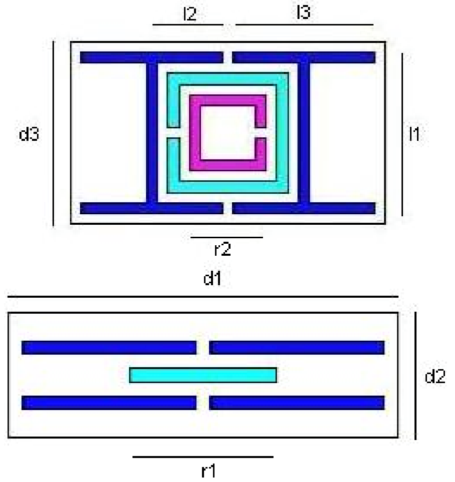


Fig. 1. Simplified nonplanar MTM geometry

This unit cell will be used as a super-substrate that will be put over a dipole antenna. This super-substrate will be made with two unit cells of different sizes (see next section). The large one will have a pass band in a certain frequency and the smaller one will have its pass band at a higher frequency. Therefore, when the larger cell allows the power transmission, the smaller will reflect it, and vice-versa.

The larger structure (see Fig. 1) was simulated with the normal incidence unit cell PEC-PMC waveguide configuration in HFSS. The magnitudes and phases of the HFSS-predicted values of S_{11} and S_{21} are shown in Fig 2 (a) and (b). The response has only one feature that occurs at 9.5782 GHz. The phases go to zero where the S_{21} magnitude approaches one.

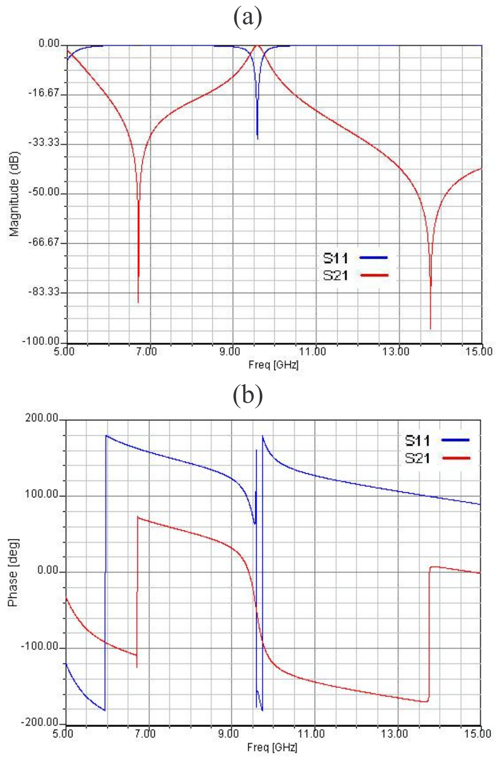


Fig. 2. HFSS predicted S parameters for the big simplified unit cell. (a) magnitudes (b) phases

Then, in order to move the S_{21} peak to a higher frequency, the unit cell will be scaled. The new unit cell is 0.8 times smaller than the first one. Two resonant frequencies can be observed at 5.88 and 11.98 GHz. The 9.5782 GHz frequency peak has been moved to 11.98 GHz.

III. DIPOLE SUPER-SUBSTRATE CONFIGURATIONS

Once the response of this unit cell is known, different types of super-substrate configurations will be fed with a dipole antenna and analysed in order to determine their radiation pattern features.

First of all, a simple $\lambda/2$ dipole working at 9.57 GHz has been designed. The dipole has a length of 10.5422 mm and it is put in the middle of a substrate of $\varepsilon_r=2.2$ and d=1.4478 mm in thickness without a ground plane. The dipole is fed by a gap source HFSS and its impedance has been optimised to have high resonance (-20 dB @ 9.57 GHz). This impedance has a value of 25.78 Ω. The dipole resonant frequency has been designed to have the same frequency as the MTM unit cell. This unit cell will be used as super-substrate over the dipole.

A. Dipole antenna with a uniform super-substrate

At the beginning, the radiation properties of the dipole with a uniform super-substrate over it were analysed (see Fig. 3). The super-substrate is formed by 18 unit cells as described in previous section. The size of the structure in λ terms is about $l_x=0.708\ \lambda$ in x direction, $l_y=0.576\ \lambda$ in y direction and $l_z=0.245\ \lambda$ in z direction. As the structure is symmetrical, it has been analysed by taking into account its electromagnetically symmetry properties to reduce computation time under Ansoft-HFSS software.

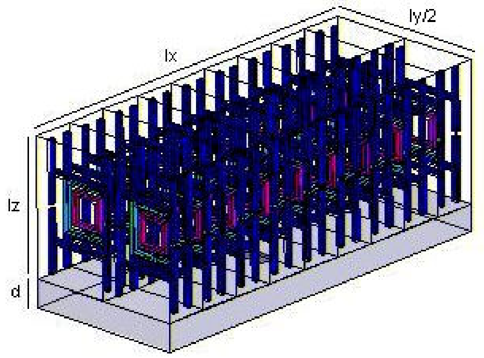


Fig. 3. Dipole antenna with a uniform super-substrate

If the resonant frequency of the whole structure is analysed, a change with respect to the resonant frequency of the dipole and the MTM unit cell can be observed. The reason for this is that the unit cell was analysed under normal incidence condition and now a dipole antenna has been used as a feeder. The MTM structure together with the dipole antenna form a new configuration with new properties, which will be presented later on. The S_{11} and directivity values of this configuration as function of the frequency can be seen in Fig. 4. The better adaptation value is about –9.76 dB at 9.8 GHz and the maximum directivity obtained is 7.6 dB at 9.92 GHz.

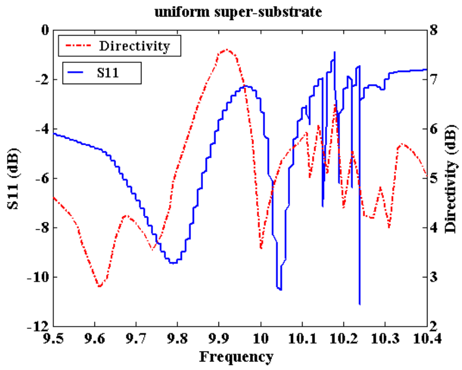
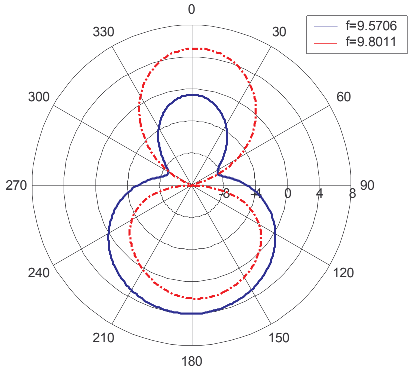


Fig. 4. Directivity and S_{11} vs frequency

In order to compare this structure with the other structures analysed, radiation patterns at different frequencies are shown (see Fig. 5). Only H-plane patterns are presented as being the most restrictive. Although the directivity is very good, it will be seen that these radiation patterns are worse than radiation patterns achieved in the following sections. In this case, a considerable amount of back radiation is obtained for all the frequency points shown in Fig. 5 with smaller values where maximum directivity is achieved. It is observed that minimum S_{11} and maximum directivity frequency points do not coincide. In this way, further investigations will be performed.



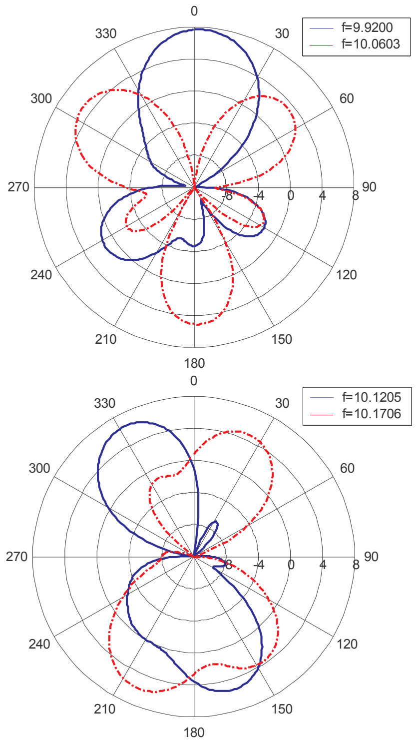


Fig. 5. Radiation patterns at different frequencies

In order to control the radiation properties of this configuration, we can vary the size of the cells that we put over the dipole. In this way, we can control how much power is transmitted and the directivity value of the radiation pattern. In this study, how these parameters change for two different configurations of MTM's has been analysed.

B. Dipole antenna with a super-substrate with large cells in the middle

Firstly, placing larger size cells just on top of the dipole and smaller ones at corner sides (see Fig. 6), improved radiation patterns can be obtained (i.e., less back radiation). This is because of the fact that S_{11} is better than in the previous case with more or less the same directivity. The number of central cells has been varied from one to five and they have been enclosed with small cells that reflect the power. The best properties are obtained for the case shown in Fig.6. This structure corresponds with the case of four large central cells surrounded by six small ones.

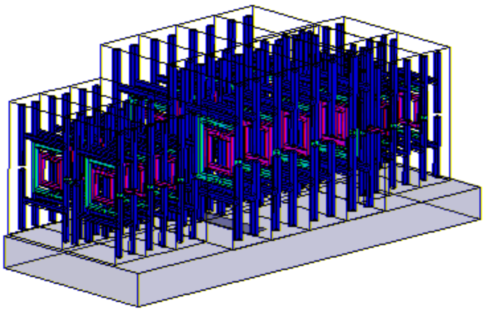


Fig. 6. Dipole antenna with a super-substrate formed by four big central cells surrounded by three small ones at each end

The S_{11} behaviour together with the directivity dependence with frequency are plotted in Fig. 7. The whole structure has a new resonant frequency that occurs at 10.02 GHz. When the resonant frequency of the dipole and the structure coincide, the transmitted power is at its maximum, and the directivity tends to be at its highest too.

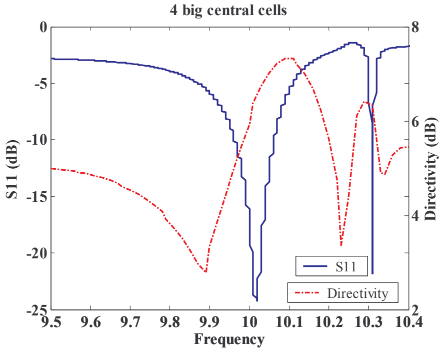


Fig. 7. Directivity and S_{11} vs frequency

Maximum directivity values around 7.3 dB are obtained at 10.1 GHz. If they are compared to a conventional dipole (with a directivity about 2 dB) an enhancement of 5.3 dB is found.

Analysing the radiation pattern features for different frequencies, it can be observed that when the frequency is out of the resonant frequency, the power is reflected and a high back radiation is obteined. However, when the frequency is close to the resonant frequency, most of the power is radiated to the bore-sight direction (resonant structure effect). Radiation patterns are shown in Fig. 8.

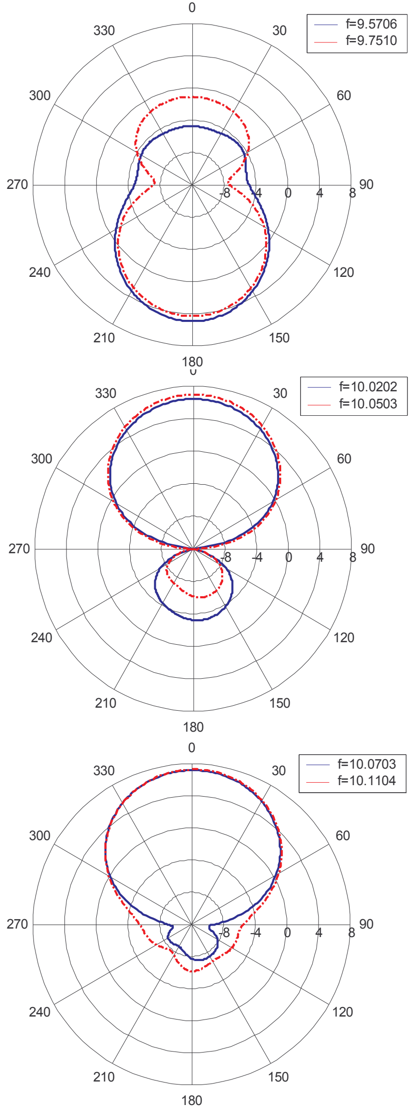


Fig. 8.Radiation patterns at different frequencies

C. Dipole antenna with a super-substrate with small cells in the middle

Secondly, the reverse structure is analysed; small cells surrounding by larger ones. As in the previous case, the number of small cells is varied from one to five. The configuration is shown in Fig. 9. In this case, four small central cells surrounded by six larger ones can be seen.

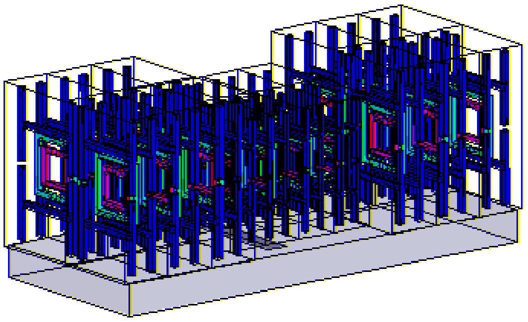


Fig. 9. Dipole antenna with a super-substrate formed by four small central cells surrounded by three large ones at each end

As in the previous case, it can be observed that the smaller the reflected power (S_{11}), the larger the directivity. In this case, a very good matching exists between both magnitudes (see Fig. 10) and it occurs at 9.88 GHz. At this frequency, the higher directivity is achieved (8 dB). Compared with the previous case, a worse S_{11} value is obtained due to the reflected cells placed just over the dipole.

At 10.1 GHz the directivity is quite good (around 7 dB), however, as the S_{11} is high (about -2 dB), high back radiation is obtained because it is out of the resonant frequency of the structure. The directivity and S_{11} dependence with the frequency are plotted in Fig 10.

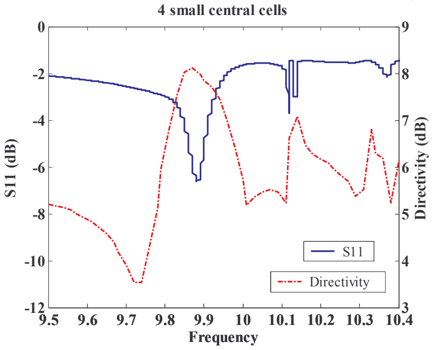


Fig. 10. Directivity and S_{11} vs frequency

In this case, the super-substrate behaves as a radiating system (array configuration) formed by two antennas (the two larger cells). Depending on the frequency, the contribution of both antennas can be added in phase or in counterphase. So, in spite of it being in the stop band frequencies of the small central cells, a main lobe to the bore-sight direction, besides of the two lateral lobes, can be observed (array effect) as well. This effect occurs when the contribution of both antennas are added in phase.

If the contributions add in opposite phase, around 10.115 GHz, a zero in the radiation pattern to the bore-sight direction can be seen. In this case, due to the pass band of the big cells, only the two lateral lobes are observed. However, at this point, it can be seen that a lot of power is reflected because S_{11} is not very low (≈ -2 dB), i.e. the back radiation is high. The results are shown in Fig. 11 where the radiation patterns at different frequencies are plotted.

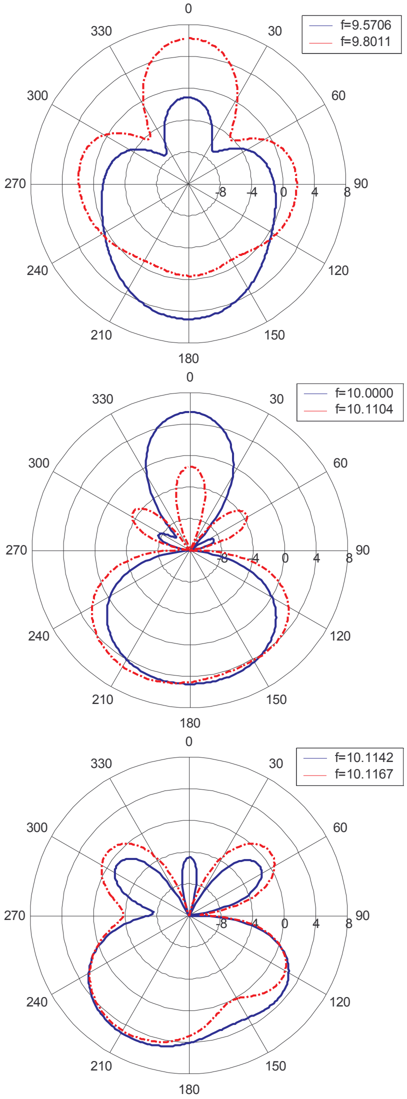


Fig. 11. Radiation patterns at different frequencies

IV. CONCLUSIONS

In this work, pass band property of left handed materials have been analysed and used to achieve radiation patterns with certain characteristics. It has been demonstrated that by putting different types of cells with pass band or stop band over the dipole, radiation patterns with enhanced properties at bore-sight direction can be obtained.

The proposed structures can open new possibilities in the implementation of antennas. As this is only the very beginning, more studies have to be done in order to obtain the best combination of unit cells. There are many possible structures which need to be analysed. To carry out this study, a Left Handed unit cell has been selected, however, there are other types of LHM cells that will be analysed in order to achieve better bandwidths and radiation properties.

REFERENCES

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